BWX TECHNOLOGIES INCORPORATED

RESEARCH & TEST REACTOR FUEL ELEMENTS (RTRFE)

RERTR ANNUAL MEETING, BUDAPEST HUNGARY

October 1999

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BWX Technologies Progress with Reduced Enrichment Fuel Production

(HIGH DENSITY FUELS)

ABSTRACT

BWX Technologies Inc. (BWXT) has experienced several production improvements over the past year. The homogeneity yields in 4.8 gU/cc U_3Si_2 plates have increased over last year's already high yields. Through teamwork and innovative manufacturing techniques, maintaining high quality surface finishes on plates and elements is becoming easier and less expensive. Currently, BWXT is designing a fabrication development plan to reach a fuel loading of 9 gU/cc within 2 - 4 years. This development will involve a step approach requested by ANL to produce plates using U-8Mo at a loading of 6 gU/cc first and qualify the fuel at those levels. In achieving the goal of a very high-density fuel loading of 9 gU/cc, BWXT is considering employing several new, state of the art, ultrasonic testing techniques for fuel core evaluation.

OVERVIEW OF BWX TECHNOLOGIES INC.

BWXT has over twenty years of history in providing quality fuel elements to research and test reactors throughout the world. BWX Technologies Inc. is located in rural Virginia and employs a staff of over 1,300 personnel. A strong engineering group provides the backbone of support for producing fuel components for nuclear reactors. With 40,000 square feet of operating floor space, BWXT fabricates a variety of different types of nuclear production and energy system components and processes. Currently, BWXT is also producing Mo-99 targets for use in reactors outside the United States. While BWXT is primarily a production facility, a considerable amount of research and development on manufacturing processes is always underway. BWXT demonstrated ability to meet the highly technical fabrication requirements for the production of superconducting magnets. Fuel handling and processing are also some of BWXT's many functions. Currently, BWXT is down-blending HEU to LEU for later commercial use.

Current contracts in the Research & Test Reactor Fuel Element Unit (RTRFE) range from Universities in the United States to International Laboratories overseas. BWXT currently maintains fuel production qualification for several Japanese reactors and has qualified as a fuel provider for other reactors in Europe. Fuel types include: high and low enriched uranium in the forms of U_3O_8, UAl_x, and U_3Si_2 (LEU only). Over the past 12 months, RTRFE has fabricated over 11,000 fuel plates for domestic and international reactors.

RECENT MANUFACTURING CONSIDERATIONS

Homogeneity has continued to improve above expectations, maintaining surface quality of plates and elements has become simpler, and strides have been taken to further integrate the experience and knowledge of fabrication personnel and engineers with the ultimate quality of the fuel elements.

Homogeneity

Homogeneity of high-density fuels in aluminum matrix is one of the most difficult attributes to achieve. Over the past year, BWXT has had substantial success with homogeneity in high loaded 4.8 gU/cc cores. The yield now exceeds 99% for homogeneity for the high loaded U_3Si_2. With low variation of fuel distribution, RTRFE is able to create a reasonable "picture" of what a nominal fuel distribution will look like and then further evaluate where and how variations occur.

Homogeneity Cont.

Out of the most recent 500 production plates produced with U_3Si_2 at a high loading, the only conditions (occurring in 3 plates) outside of the nominal requirements were a differential loading of over 15% in one area on only one end of the fuel. By reviewing the remaining data for the fuel plate it was evident that the plate was homogeneous with the exception of the specific area. After further analysis, the condition was identified not to have been created by the fuel powder itself or plate processing but, by the actual loading of the fuel powder into the die cavity during compaction. If the overall quality of the fuel homogeneity had not been so high, identification of the cause of this condition would not have been possible. This example of process characterization demonstrates the ability to optimize the process and maintain high quality fuel plates.

Surface Quality

6061 is a relatively strong aluminum alloy, but compared to other materials such as tool steel, it is a soft metal. The surface is easily damaged and constant care and monitoring are required to ensure the final surfaces are free from surface imperfections. When a surface discontinuity is discovered, the condition is traced to the cause and the condition is then characterized. If the condition is caused by equipment, then that potential for causing a surface condition is considered a part of the equipment characterization until the cause can be repaired. This allows review on a broad scale of the total process potential for the fabrication shop.

BWXT has monitored the handling and processing conditions for fuel plates in RTRFE for many years. BWXT now controls the type of hand coverings worn, the quality of the surface that any product is placed on and even the type and quality of protective covering that the product is in contact with. The fuel plate and element is not contacted by human hands after the cold rolling process to ensure that no fingerprints are evident in the final product. All of the shop personnel are trained to ensure that the surfaces of all components are of the highest quality.

Final Quality Responsibility

RTRFE has a manufacturing team made up of managers, engineers, and shop personnel working together to assure the highest quality components possible. The shop personnel have been empowered to make suggestions to improve both the fabrication process and their own work environment. RTRFE requests that operators who are experienced in particular operations become more cognizant of those operations and become more active in improving those processes.

DEVELOPMENT 2000

BWXT is procuring development funding to be used to develop and evaluate processing techniques for Uranium Molybdenum fuel (U-8Mo) in RTRFE fuel assemblies. Two studies are currently under consideration. The first study is to produce fuel plates at 6 gU/cc loading and the second study is to utilize the same fuel at 9gU/cc loading. The relationship of the fuel loading to volume for different fuels is shown on Figure I below. The small triangle on the lower left quadrant represents the area of feasibility for candidate fuels.

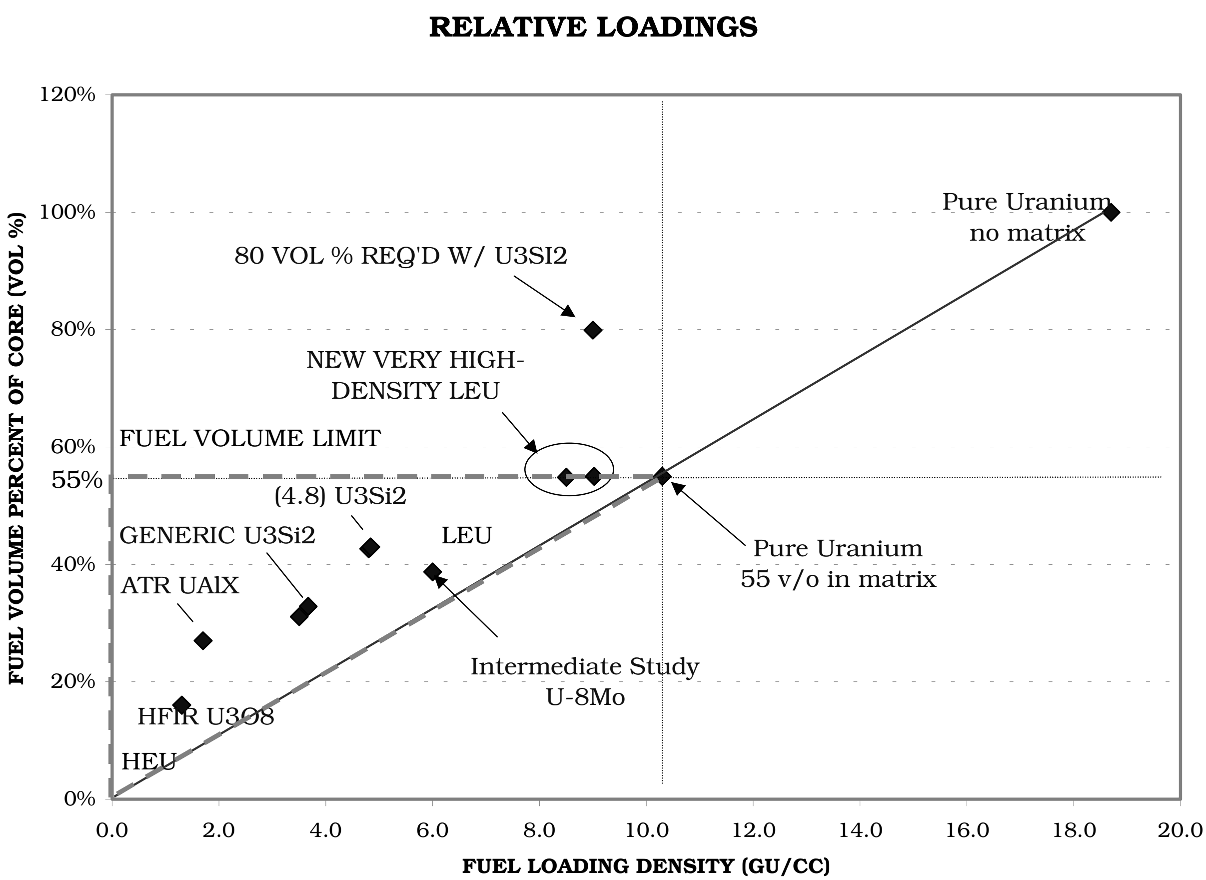

FIGURE I

The upper left quadrant requires too high a volume loading (>55 vol. %) for any given fuel compound. The area to the right of the diagonal requires greater than 100% uranium which is not feasible. Testing fuel that will fit into the highest and rightmost corner area is desirable but is also the most challenging. Today, fabrication of the LEU U_3Si_2 at 4.8 gU/cc is in production and is the most cost effective high-density product available.

DEVELOPMENT 2000 Cont.

The long-term goal of developing U-8Mo fuel is to produce a viable fabrication process for very high-density (VHD) fuels at a uranium loading of 9 gU/cc. This two-phase development study will test U-8Mo fuel at an intermediate loading density of 6 gU/cc. If success is achieved using the U-8Mo at a lower loading, a follow-up study will be pursued to increase the loading to 9 gU/cc at a later date. Two studies of this development are being performed for several reasons. The qualification of U-8Mo fuel at the lower density, 6 gU/cc, will allow many reactors to convert to a reprocessable LEU fuel alloy at an earlier date. Reactors currently using U_3Si_2 LEU will be able to convert to a reprocessable fuel. Phase II of this development, test element fabrication, will be to produce test fuel elements for irradiation in a reactor designated by ANL. Studies for fuel loading at 9 gU/cc will be considered after successful fabrication of fuel plates at the 6 gU/cc loading.

Development Challenges

Fuel fabrication at very high densities will be difficult. The concept of developing a process at 6 gU/cc then increasing to 9 gU/cc will be advantageous. A number of potential processing problems will be identified during the much lower volume fraction of 6 gU/cc that will apply to 9 gU/cc. The proclivity for the fuel to oxidize during hot roll will be one item that may be worked out at the lower volume fraction. An idea of how well an extremely dense atomized powder will perform from a segregation standpoint will also be an issue. Homogeneity is expected to give the most amount of difficulty relative to any of the other parameters.

Another challenging issue is the concept of vertical segregation. This condition is typically only detectable during destructive evaluation. When fuel is poured into the die cavity, the fuel tends to fall through the matrix and accumulate at the bottom of the die. This is shown in Figure II at the right in a fuel plate made with comminuted fuel. The effect is only slight and easy to control, but the potential for vertical segregation in atomized plates of extremely high density will be evaluated.

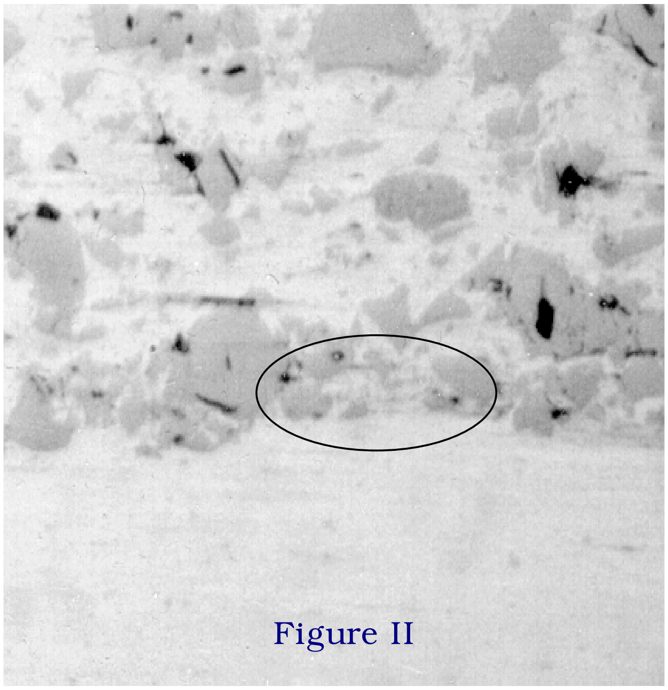

Figure II

ULTRASONIC TESTING FOR FUTURE FUELS

During production of high density fuel plates using materials such as U_3Si_2 or materials with greater densities, there is the tendency for fuel to accumulate at the end of the fuel plate in a region called the "dog-bone". This dense accumulation of particles may result in the ultrasonic inspection results showing indications which appear similar to clad unbonds. This condition is caused during the application of the fuel powder to the die during compaction. For standard, low/high density product, BWXT overcame this problem many years ago. In a very small sample of plates, fabricated from U_3Si_2 at 4.8 gU/cc, ultrasonic inspection produced indications that were verified to be small amounts of crushed fuel particles in localized end region areas, not a potentially typical "unbond" indication. Today, fuel end region unbond conditions are less than 0.5 % of total fuel plates and is not considered a problem. However, when the fuel density is increased the ultrasonic signals are attenuated which present new problems in verification of bond quality.

Ultrasonic Inspection Development

The ultrasonic transducers and techniques that work well to evaluate bond in the main body of the fuel do not work as well in the core end region of the fuel where the density of the plate abruptly changes. Even when the fuel is tapered considerably, most current methods for bond evaluation do not provide an acceptable scan at very high densities, i.e. 9 gU/cc. For future ultrasonic inspection, BWXT considers this a challenge to provide proper evaluation of the very high-density plates. BWXT is currently evaluating Ultrasonic Imaging to provide both min-clad, unbond, and homogeneity analysis of the fuel plates. Developmental plates will be prepared using a 9 gU/cc surrogate (Tungsten) non-fuel core to develop the parameters and methods for analysis.

Ultrasonic Imaging uses conventional pulse-echo and thru-transmission scanning techniques. The use of these techniques and the recording of the digital waveforms will allow peak amplitude and time-of-flight data analysis. Peak amplitude analysis evaluates and compares the amplitude of the ultrasonic signal throughout the inspected area. Time-of-flight analysis evaluates the amount of time it takes for the ultrasonic soundwaves to transmit into the plate, reflect from the back surface, and return to the transducer throughout the inspected area. For high-density fuels, the attenuation of the material increases resulting in a loss of sound transmission into the component. Lower frequency transducers are generally employed to allow sound penetration into the material, but this results in a loss of resolution and sensitivity. To provide ultrasonic inspection capabilities for the high density fuels, the higher frequency transducers used with

Ultrasonic Inspection Development cont.

pulse-echo and thru-transmission techniques require the capabilities of the computers imaging. The computers analysis system will allow low level ultrasonic signals to be processed into meaningful data.

Analysis of min-clad, unbond, and homogeneity data requires digitally recorded ultrasonic waveforms from the component inspections. Real time or off-line image analysis can be performed from waveforms using the time-of-flight or peak amplitude data. Cross-section clad and core evaluations can be made by evaluating “waveform slices” throughout the plate thickness. The data can also be translated into a three-dimensional model showing greater detail of the clad thickness profile, homogeneity, and fuel dispersion of the fuel core.

Figure III below shows the minimum cladding map of a small test fuel plate. Using computer image analysis, a clad “slice”, or a specific thickness, was analyzed from the digital data taken from a cross-sectional thickness of a plate. The light area circled displays the thinner clad regions. The resolution of the area is less than 0.1 mm and smaller resolutions and sensitivities are possible depending on transducer selection and scanning increments.

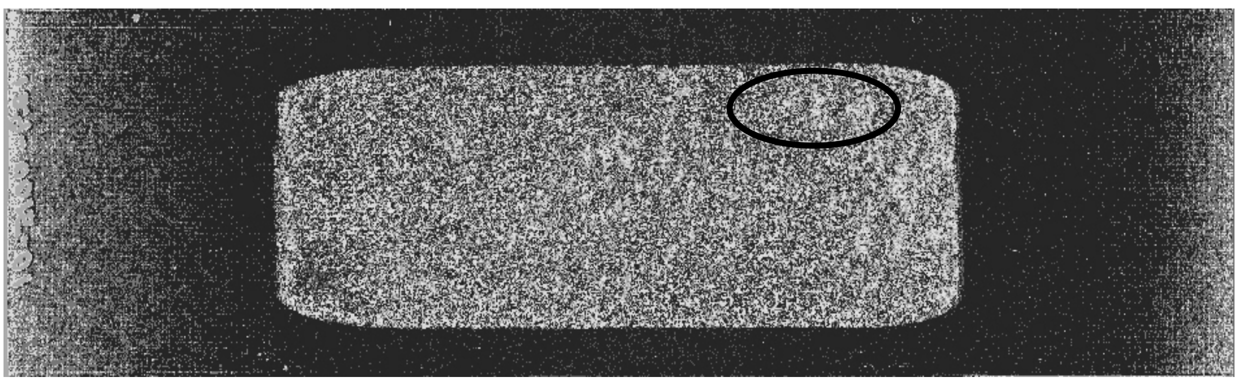

Figure III

One of the most useful aspects of using Ultrasonic Imaging is the potential for information on irradiation testing samples, especially bonded samples (i.e. mini plates) by modeling the fuel core. The internal structure of the fuel can be evaluated based on concentrations and locations of both large and small fuel particles. The data would serve as permanent record of the location for fuel and would be particularly useful for post irradiation comparison. This method could also be used to replace the destructive evaluation (DE) typically performed. Once baseline ultrasonic inspection and image development has been performed, the potential for cost savings and scrap disposal savings could be significant.

SUMMARY

BWXT is actively involved in the manufacturing development of new very high-density fuels for domestic and international research and test reactors. The challenges are considerable, but the outcome of increased technology and capabilities of research reactor providers are important to fuel users. The cooperation of Argonne National Laboratory and Korea Atomic Energy Research Institute is greatly appreciated and has provided much needed insight and fuels.

The first phase of the development effort is scheduled for completion by June 2000 with results available after August of the same year. Inspection development including Ultrasonic Imaging should new technologies are brought to fruition. Any reactor operator or researcher interested in more information should contact BWX Technologies Inc.